MONOLITHIC CONCRETE HOUSE

A Construction Manual

Site Selection Through Occupancy, for a 150-Year Structure

Site-specific values, bearing capacity, frost depth, wind and seismic load, solar geometry, require verification by a licensed architect, structural engineer, and geotechnical engineer. Figures given here are planning ranges, not design values.

Contents

How to Use This Manual 3
Section 1. Project Definition and Design Philosophy 4
Section 2. Site Selection Criteria 6
Section 3. Geotechnical Investigation 7
Section 4. Assembling the Design and Construction Team 8
Section 5. Architectural and Structural Design 10
Section 6. Energy Modeling 12
Section 7. Permitting and Code Compliance 13
Section 8. Site Preparation and Excavation 14
Section 9. Foundation Systems 15
Section 10. The Concrete Shell: Wall Construction 17
Section 11. Concrete Mix Design and Curing 20
Section 12. Roof System 22
Section 13. Windows, Glazing, and Passive Solar Design 24
Section 14. Heating and Cooling 26
Section 15. Ventilation 28
Section 16. Water Systems 29
Section 17. Electrical and Power Systems 30
Section 18. Interior Construction 31
Section 19. The Library 32
Section 20. Acoustic Design 33
Section 21. Landscaping and Site Water Management 34
Section 22. Testing and Commissioning 35
Section 23. Maintenance Schedule 36
Section 24. Budget Framework 37
Section 25. Timeline 39
Section 26. Common and Costly Mistakes 40
Appendix A. Design and Construction Team Checklist 41
Appendix B. Glossary 42

How to Use This Manual

This manual describes how to design and build a single-story monolithic concrete house. The design target is a service life of 150 years or more for the structural shell, with mechanical and electrical systems replaced on much shorter cycles.

The instructions are general. They apply across a range of sites and climates. Site-specific values (soil bearing capacity, frost depth, wind load, seismic category, solar geometry) must come from a licensed geotechnical engineer, structural engineer, and energy consultant working on the actual lot. Numbers given here are planning ranges, not design values. No figure in this manual belongs on a stamped drawing or a permit application without independent verification by a licensed professional in the relevant jurisdiction.

The sections follow the order most projects use in practice: site analysis, design, permitting, foundation, shell, envelope, systems, interior, landscape, commissioning, and maintenance. Some phases overlap. Design and permitting typically run in parallel with early site work, and mechanical rough-in overlaps with interior construction.

Each section states what decision is being made, what drives that decision, and what a typical range looks like. Where a step legally requires a licensed professional in most jurisdictions, that requirement is stated directly rather than implied.

Section 1. Project Definition and Design Philosophy

The building type described here is a bearing-wall concrete structure, single story, built to resist decay, fire, wind, and water intrusion well beyond the 30-to-50-year design life typical of wood-framed construction. The example floor plan used throughout this manual is approximately 2,000 square feet: a library and office, living and dining space, kitchen, two bedrooms, two bathrooms, and a centralized mechanical room, arranged around a small interior courtyard. The same principles apply at smaller or larger scale. Costs and system sizing scale roughly with square footage; some fixed costs (design fees, well drilling, driveway, permitting) do not.

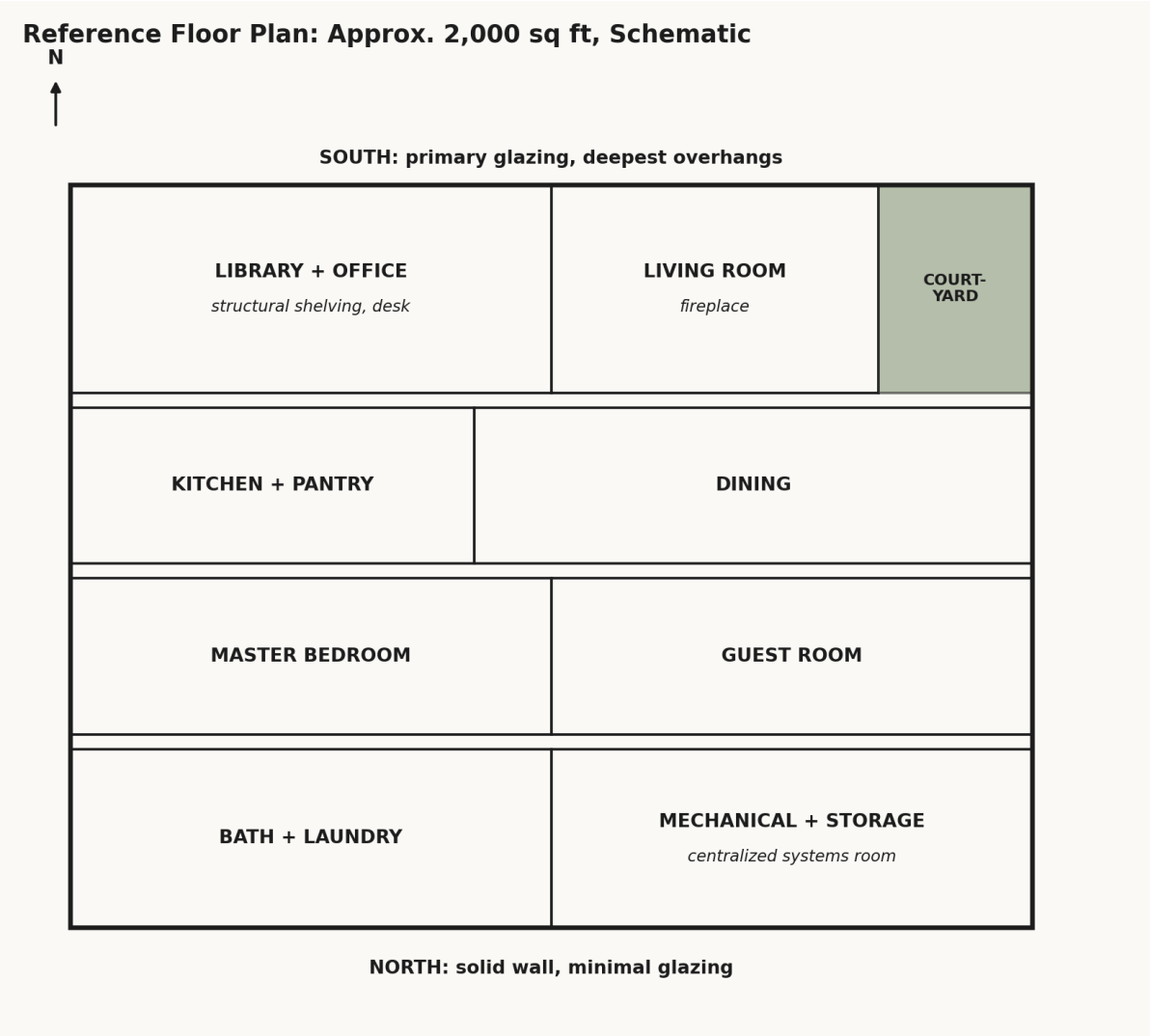

Figure. Reference floor plan: approximately 2,000 square feet, organized around a central courtyard

Two decisions define the project and should be fixed before anything else.

The shell is permanent. The foundation, bearing walls, and roof slab are designed to outlast every other component of the house, including every mechanical system, every window, and most interior finishes. This means the

shell is over-specified relative to code minimums, and every penetration through it (conduit, plumbing sleeves, duct chases) is planned before the pour, not cut in afterward.

Thermal mass is exposed to the interior, not buried inside the wall assembly. This has a direct consequence for which wall construction method is used, covered in Section 10. Getting this wrong is the most common conceptual error in concrete house design: choosing a wall system that insulates the concrete from room air defeats the purpose of building in concrete at all.

Everything else, room layout, roof shape, interior materials, landscape design, is a preference decision and is treated as adjustable in this manual. The sections that follow concentrate on the parts of the project that are difficult or impossible to change once built: the shell, the envelope, and the buried infrastructure.

Section 2. Site Selection Criteria

A concrete house is more sensitive to site conditions than a comparable wood-framed house, because of its weight and its performance targets.

Slope and drainage. A gentle south-facing slope sheds water away from the foundation by gravity and improves solar access. Flat sites work but need engineered grading to move water away from the building on all sides. Avoid sites at the base of a slope, where water concentrates, and avoid any site inside a mapped floodplain.

Soil and groundwater. Bearing capacity, water table depth, and soil type determine foundation design and cost before any other factor does. A site requiring piles or an engineered mat foundation because of poor soil can add tens of thousands of dollars to the foundation budget. This is evaluated formally in Section 3, but a preliminary sense of the soil, from neighbors, public soil survey maps, or drainage behavior after rain, is worth gathering before committing to a parcel of land.

Solar orientation. The long axis of the house should run east-west, placing the long facades north and south. The south facade carries the most glazing and the deepest overhangs; the north facade is mostly solid wall. A site with unobstructed southern sky, no ridgeline, tree line, or adjacent building within roughly 30 degrees of true south, is close to ideal. Significant southern obstruction is workable but increases the mechanical heating contribution needed to compensate for lost passive gain.

Wildfire and defensible space. In fire-prone regions, concrete construction is a genuine advantage, since the structure itself does not burn. Site selection should still account for defensible-space guidelines, typically a minimum of 30 to 100 feet of managed vegetation clearance around the structure depending on jurisdiction and fuel type, and for ember-resistant venting, since a fire-hardened shell with unscreened vents or a combustible roof edge is only partially protected.

Construction access. Concrete work depends on ready-mix truck access and, where a pump truck is required, adequate turning radius and reach. A remote or narrow-access site adds line-pumping cost and may reduce the number of contractors willing to bid the work at all.

Utilities. Confirm what exists at the property line: grid power, telecommunications, and whether municipal water and sewer are available or a well and septic system will be required. Off-grid-capable systems, covered in Sections 16 and 17, reduce dependence on utility connections but do not remove the need for a code-compliant water and waste plan.

Section 3. Geotechnical Investigation

A geotechnical engineer must be engaged before the foundation is designed. This is not optional at this weight class. A monolithic concrete house with thick bearing walls and a concrete roof slab can weigh several hundred tons, and foundation design depends entirely on what the soil beneath it can support.

Scope of the investigation:

- Soil borings or test pits at multiple points across the building footprint, to a depth below the anticipated frost line and below the zone affected by foundation loads.
- Standard Penetration Test (SPT) or Cone Penetration Test (CPT) data, used to estimate soil bearing capacity and stiffness.
- Groundwater table depth, measured directly or estimated from regional data, since a high water table affects both foundation design and waterproofing strategy.
- Percolation testing, if a septic system is planned.
- Frost depth for the region, which sets minimum footing depth in cold climates.
- Seismic site class, required as a structural design input in most jurisdictions, including regions of low seismicity.

The output is a geotechnical report: an allowable bearing capacity, in pounds per square foot or kilopascals, a recommended footing depth, any recommendation for soil improvement such as over-excavation and recompaction where near-surface soil is too soft, and flags for special conditions such as expansive clay, fill soil, a high water table, or slope instability.

This report goes directly to the structural engineer, who uses it to size footings. Skipping this step and using footing dimensions from a generic table is the most common cause of foundation settlement and cracking in heavy construction.

Section 4. Assembling the Design and Construction Team

This project needs more disciplines than a standard wood-framed house, and each has a distinct role.

- **Architect.** Ideally one with direct experience in cast-in-place or ICF concrete residential work, not only steel or commercial concrete. Concrete detailing, form-tie pattern, control joints, window bucks, differs enough from wood-frame detailing that general residential experience is not a substitute.
- **Structural engineer.** Licensed in the jurisdiction of construction. Performs load calculations, footing design, wall reinforcement schedule, and roof slab design, and stamps the drawings for permit.
- **Geotechnical engineer.** Covered in Section 3.
- **Energy consultant or Passive House-trained designer.** Not required by code in most places. Valuable given this level of insulation and airtightness. Runs the whole-building energy model in Section 6 and helps avoid the moisture and overheating risks that come with high-mass, high-insulation assemblies designed without modeling.
- **General contractor.** Must have direct experience pouring architectural, exposed-finish concrete, not only utilitarian foundation work. Ask to see completed projects with exposed board-formed or site-formed concrete walls, and talk to those clients about surface quality and schedule adherence.
- **Concrete subcontractor or formwork crew.** On many projects a specialist separate from the general contractor, particularly for architectural finish work, since form-tie pattern and pour sequencing affect the final appearance permanently.
- **Mechanical designer.** Sizes the ground-source heat pump system, ventilation, and radiant floor distribution. A Manual J load calculation, the standard North American heating and cooling load method, should be run specifically for this envelope rather than assumed from a rule of thumb, since a well-insulated concrete house has a much lower load per square foot than a standard wood-framed house of the same size.
- **Well driller, septic designer, solar installer, and geothermal loop contractor**, as the site requires.

Sequencing the team matters. The geotechnical engineer should be engaged before the architectural design is finalized, since foundation type can constrain the floor plan directly, for example where a pile foundation on poor soil limits where interior bearing walls can land. The energy consultant should be involved during design, not after, since window sizing, overhang depth, and wall assembly are energy decisions as much as architectural ones.

Section 5. Architectural and Structural Design

The architectural drawings define the floor plan, elevations, window and door locations, and material specifications. For this building type, three decisions carry more structural weight than they would in a conventional house.

Room layout and bearing walls. In a concrete bearing-wall structure, interior walls that carry roof load are structural, not partitions. The floor plan should be developed together with the structural engineer from an early stage, since relocating a load-bearing interior wall after the structural design is finalized is far more disruptive than in wood framing.

Roof span. A flat or low-slope concrete roof slab spans between bearing walls. Longer spans need thicker slabs, additional interior bearing walls, or beams. A roughly 2,000-square-foot single-story plan with a reasonable number of interior bearing walls, as in the reference layout, typically keeps spans within a range a standard reinforced slab handles without unusual depth. An open-plan design with very long clear spans requires the structural engineer to specify a deeper slab, added beams, or steel concentrated at midspan.

Window and door openings. Every opening in a bearing wall interrupts the load path and needs a lintel, a reinforced concrete beam above the opening, sized to carry the wall and roof load above it back to the adjacent solid wall. Large openings, closely spaced openings, and openings near corners all increase lintel size and cost. Architectural intent (a long run of glazing) and structural cost interact directly here, and lintel implications are worth discussing with the structural engineer before the elevations are finalized.

Estimating structural load, as an illustration. The following worked example shows how the numbers in this building type add up. It is illustrative only. It is not a substitute for the structural engineer's calculation, which uses actual wall thickness, actual roof assembly, snow load, and wind load for the specific design and location.

Assume normal-weight concrete at 145 to 150 pounds per cubic foot, for a roughly 2,000-square-foot single-story house with a perimeter of about 180 linear feet, 9-foot bearing walls at 12 inches thick, an 8-inch roof slab, and a partial green roof over half the area.

- Bearing walls: about 1,600 square feet of wall area at 1 foot thick, roughly 240,000 pounds, or about 120 tons.
- Roof slab: 2,000 square feet at 8 inches (0.67 feet) thick, roughly 200,000 pounds, or about 100 tons.
- Green roof growing medium, saturated, over half the roof area at 6 inches deep: roughly 45,000 pounds, or about 22 tons.

- Foundation walls and footings: order of magnitude similar to the above-grade walls, roughly 100 to 150 tons depending on depth and footing size.
- Interior slab-on-grade or elevated floor slab, if present: roughly 75 to 100 tons for a comparable thickness across the full footprint.

Total, order of magnitude: 450 to 650 tons, before interior finishes, mechanical equipment, and furnishings. This is why the geotechnical report in Section 3 is not a formality. Soil that comfortably supports a wood-framed house at 15 to 20 tons total dead load can be entirely inadequate for a structure five to ten times heavier on the same footprint.

Wind and seismic. Even in regions of low seismic activity, most codes require a seismic design category assignment and corresponding detailing, including minimum reinforcement ratios and connection details between roof slab and walls. Wind load governs uplift and lateral design in many regions and is calculated from a wind speed map and exposure category specific to the site. Both are the structural engineer's responsibility, using the geotechnical report together with local code wind and seismic maps.

Section 6. Energy Modeling

Before construction drawings are finalized, a whole-building energy model should be run, distinct from the structural engineering and usually performed by an energy consultant, a Passive House-trained designer, or a mechanical engineer using dedicated software.

What the model does. It simulates heat loss and heat gain through every wall, window, and roof assembly across a full year of weather data specific to the site, and predicts the heating and cooling load, indoor temperature swings without mechanical intervention, and, critically for this assembly type, the risk of interstitial condensation inside the wall.

Why moisture modeling matters here specifically. A thick concrete wall with continuous exterior insulation is a different moisture system than a standard wood-framed wall. The concrete itself holds a large amount of water from the pour for months after construction, and the assembly needs to be able to dry to at least one side. A hygrothermal model, commonly run with WUFI or an equivalent tool, checks whether the assembly as designed dries out over an annual cycle rather than accumulating moisture year over year. Skipping this step on a high-mass, high-insulation assembly is a common cause of concealed mold, or, over a longer period, of corrosion at embedded steel reached by trapped moisture.

Sizing implication. A well-modeled version of this house typically has a heating and cooling load per square foot far below a standard wood-framed house of the same size, sometimes by half or more, from the combination of thermal mass, continuous insulation, and airtightness. This affects Section 14 directly: the mechanical designer should size the ground-source heat pump from the model's output, not from a rule-of-thumb tonnage-per-square-foot figure meant for conventional construction. Oversizing a heat pump for an over-estimated load is a common and expensive mistake; an oversized system short-cycles, which lowers efficiency and shortens equipment life.

Section 7. Permitting and Code Compliance

The permitting path for this house has more steps than a standard single-family permit in most jurisdictions, because of its structural type and its systems.

Typical review components:

- Site plan review: setbacks, lot coverage, stormwater management, driveway and utility connections.
- Structural plan review: the stamped structural drawings, including foundation, wall reinforcement, and roof slab design.
- Energy code compliance: most jurisdictions require a compliance path, prescriptive, performance-based, or a Home Energy Rating System (HERS) score, demonstrating the building meets minimum energy code. A house like this one typically exceeds code minimums substantially, but the compliance path still has to be documented and submitted.
- Well and septic permits, if municipal water and sewer are unavailable, usually reviewed by a separate health or environmental department on its own timeline, often longer than the building permit itself.
- Mechanical and electrical permits, separate applications in many jurisdictions for the ground-source heat pump loop field, the solar array, and the battery system, sometimes requiring their own licensed-trade sign-off.

Unconventional-construction friction. A monolithic concrete house with a green roof, an exposed board-form interior finish, and a ground-source heat pump is familiar territory for a structural engineer. It may still be unfamiliar to a local plans examiner who mostly reviews wood-framed submissions. Budget extra time for review cycles, and expect the structural engineer or architect to field direct questions from the reviewing authority. This is normal for this building type and is not, by itself, a sign of a design problem.

Realistic timeline. Design and engineering typically run 6 to 12 months for a project of this complexity. Permitting, once complete drawings are submitted, typically runs an additional 2 to 6 months, though this varies enormously by jurisdiction: rural counties with low review volume can move faster than dense suburban jurisdictions with backlogged plan review departments.

Section 8. Site Preparation and Excavation

Clearing. Clear only what construction access and the building footprint require. Mark and protect mature trees to be retained, including their root zones; construction equipment compacting soil over a tree's root zone is a common way to kill a tree that was nominally saved.

Excavation. Foundation excavation depth is set by regional frost depth, since footings must sit below the frost line to avoid frost heave in cold climates, and by the foundation type chosen. Typical depths range from about 4 feet in mild, frost-free climates to 8 feet or more in cold climates with deep frost penetration. The geotechnical report specifies the required depth for the specific site.

Drainage during construction. Install a gravel drainage layer and perimeter footing drains as part of the excavation work, before or immediately after the foundation walls go up depending on the sequence used. Waterproof membranes are applied to the exterior face of the foundation wall once it is formed and cured, covered in Section 9.

Erosion control. Silt fencing, temporary seeding of disturbed soil, and staged clearing rather than clearing the entire site at once reduce erosion and sediment runoff during construction, and are commonly required by local stormwater permits regardless of building type.

Section 9. Foundation Systems

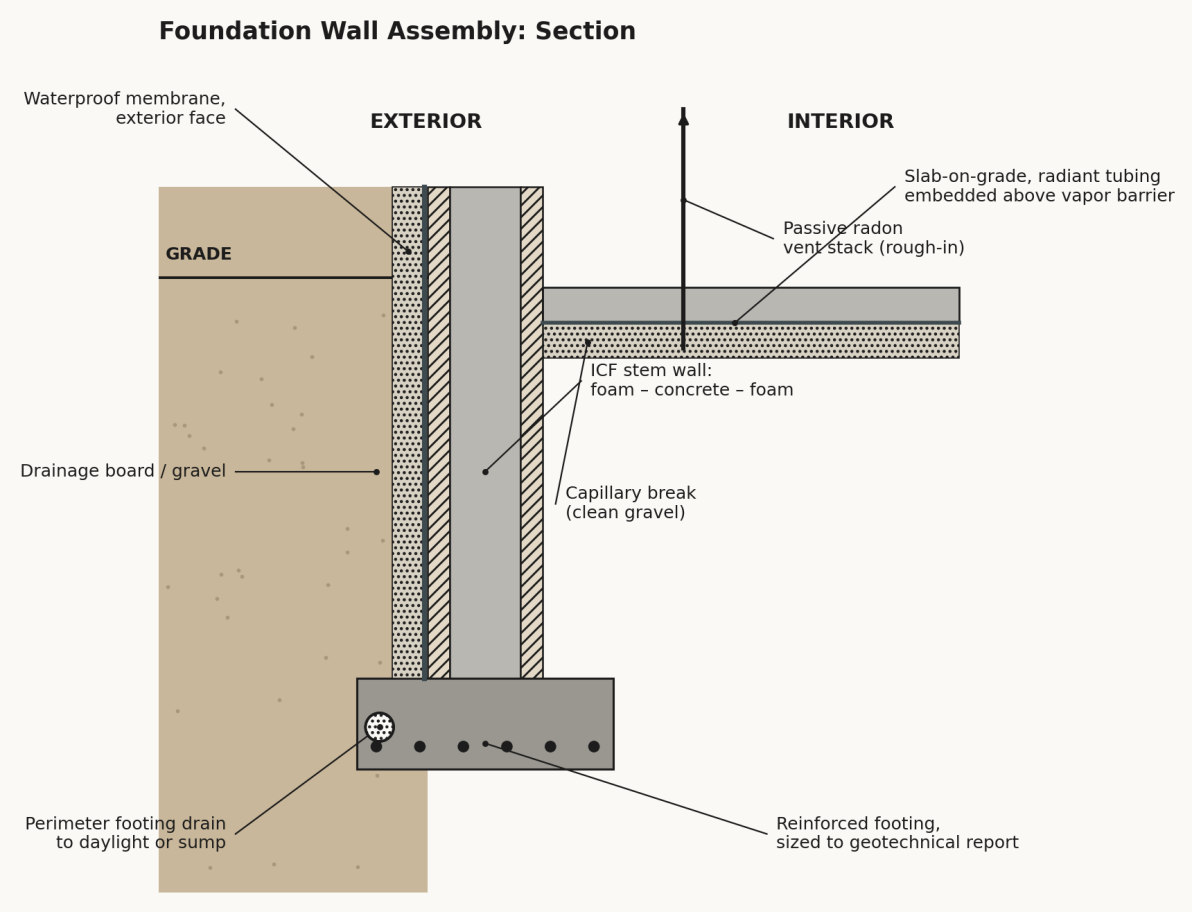
Foundation Wall Assembly: Section
Waterproof membrane, exterior face
EXTERIOR
INTERIOR
Slab-on-grade, radiant tubing embedded above vapor barrier
Passive radon vent stack (rough-in)
GRADE
ICF stem wall: foam – concrete – foam
Drainage board / gravel
Capillary break (clean gravel)
Perimeter footing drain to daylight or sump
Reinforced footing, sized to geotechnical report

Figure. Foundation wall assembly: footing, ICF stem wall, waterproofing, and drainage

Footings. Reinforced concrete footings distribute the building's weight to the soil at a bearing pressure the geotechnical report confirms the soil can support. Footing width and depth come directly from the structural engineer's calculation using that report. There is no generic footing size that applies across sites: the same building can need a 16-inch-wide footing on good soil and a 36-inch-wide footing, or a different foundation type entirely such as grade beams on piers, on poor soil.

Foundation wall system. Two systems are common for a house like this. Insulated Concrete Forms (ICF) below grade: stay-in-place foam blocks form a mold for the concrete, and once poured and cured, the foam remains as continuous insulation on both faces. This is a strong choice for foundation walls specifically, because the exposed aesthetic that matters above grade, covered in Section 10, is irrelevant below grade, and ICF simplifies achieving continuous insulation and a clean substrate for waterproofing membrane application. Traditional formed concrete without permanent insulated forms applies where the design calls for an exposed concrete basement or crawlspace wall, less common in this building type since the below-grade space is usually mechanical and storage only.

Waterproofing. This is the single most consequential below-grade decision. Damp-proofing, a sprayed or trowel-applied asphaltic coating, resists moisture vapor but not standing water. True waterproofing, a sheet-applied rubberized membrane or a fluid-applied membrane, is required wherever hydrostatic pressure is possible, which is most sites with any meaningful water table or poor drainage. A crystalline waterproofing admixture added to the concrete mix is a useful supplementary measure but does not replace an exterior membrane, since it addresses capillary movement through the concrete itself, not joints, penetrations, or cracks.

Drainage. A perimeter footing drain, a perforated pipe in a gravel bed wrapped in filter fabric running the full perimeter of the footing, collects groundwater and directs it to daylight or to a sump pump where no gravity outlet exists. This system, combined with the exterior membrane, is what keeps a below-grade space genuinely dry rather than merely damp-resistant.

Capillary break and vapor barrier. Under any slab-on-grade, a layer of clean gravel followed by a heavy vapor barrier, 10 to 15 mil polyethylene at minimum with taped and sealed seams, prevents ground moisture from wicking up through the slab. This detail is inexpensive during construction and effectively impossible to add afterward without demolishing the slab.

Radon. Regardless of regional radon risk maps, a passive sub-slab depressurization system, a perforated pipe loop under the slab connected to a vertical vent stack, should be roughed in during construction. The incremental cost at this stage is minor; retrofitting it after the slab is poured is disruptive and expensive. If radon testing after occupancy shows elevated levels, a fan can be added to the existing rough-in to make the system active.

Insulation under the slab. Rigid insulation beneath the slab, in addition to the vapor barrier, reduces heat loss into the ground and is particularly relevant where radiant floor heating is planned, since heat delivered by the radiant system should go up into the room, not down into the earth.

Section 10. The Concrete Shell: Wall Construction

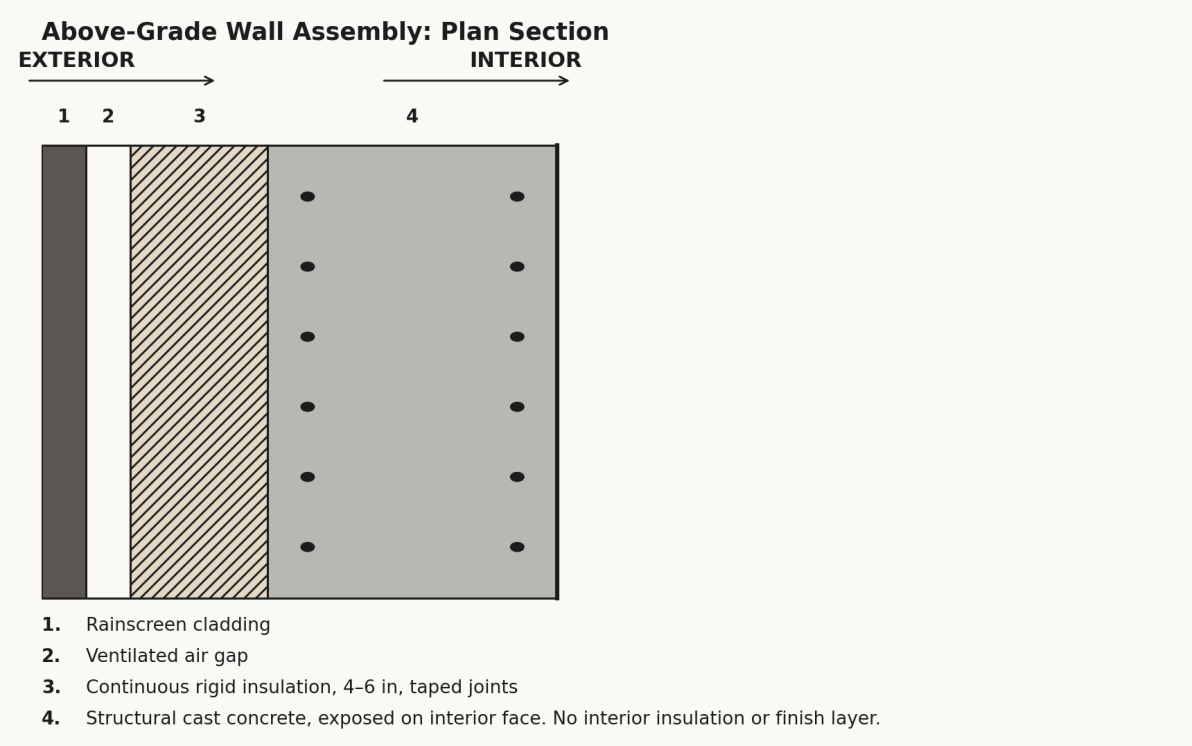

Figure. Above-grade wall assembly: exposed structural concrete, exterior continuous insulation, rainscreen cladding

This section resolves the point flagged in Section 1: the wall system used below grade is not the wall system that should be used above grade if the goal is an exposed interior concrete surface.

Standard ICF, foam-concrete-foam, insulates both faces of the concrete. This is excellent performance for a wall where neither face will be exposed, but it thermally isolates the concrete core from room air on both sides. An interior wall finished over the interior foam layer is not exposed thermal mass; it behaves, thermally, much closer to a well-insulated wood-framed wall with a concrete core that never experiences room-temperature swings. Where the intent is a concrete surface room air can actually exchange heat with, standard ICF above grade works against that intent.

The alternative, used for the above-grade walls in this design: traditional removable formwork on both faces, plywood, or board-form panels chosen for the wood-grain texture they leave behind, poured and cured, forms stripped, and continuous rigid insulation applied to the exterior face only, afterward. The interior face of the concrete becomes the finished interior wall surface directly, sealed and left as-is. The exterior insulation, commonly 4 to 6 inches of XPS, polyisocyanurate, or mineral wool board, taped and sealed at every joint, sits outside the structural wall, with a rainscreen air gap and cladding, or a direct-applied exterior finish system, over that.

This detail, insulation outside the mass, mass exposed to the interior, is the correct building-science configuration for a house designed around thermal mass, and it is also the point most likely to be gotten wrong by a contractor whose main experience is standard ICF construction. Confirm this explicitly with both the architect and the contractor before the wall system is finalized.

Board-form finish. Where plywood or board-form liners are used, the wood grain pattern transfers to the cured concrete surface and remains permanently. This becomes the finished interior wall; no additional interior finish is applied over it in rooms using this treatment. The form-tie pattern, the regularly spaced marks left by the ties holding the two form faces together during the pour, is also permanent and visible, and should be planned as a deliberate part of the design, since it cannot be removed or hidden afterward without a visible patch against an otherwise uniform surface.

Reinforcement. Steel reinforcement is placed inside the forms before the pour, per the structural engineer's schedule: bar size, spacing, concrete cover (the distance from the outer concrete surface to the steel, which protects the steel from moisture and carbonation and is a code minimum, not a preference), and lap splice lengths at bar overlaps. Corners and openings get additional reinforcement, since these are stress concentration points.

Conduits and sleeves. Every electrical conduit and plumbing sleeve that needs to pass through a concrete wall must be placed before the pour. Cutting a wall after it cures to add a missed penetration is possible but expensive, disruptive, and weakens the wall locally unless carefully engineered. This is the single most common source of change orders in concrete construction, and the fix is coordination: electrical and plumbing designs finalized and reviewed against the formwork drawings before any concrete is poured.

Thermal bridging at penetrations and edges. Any point where structural concrete passes from inside to outside without a break in the insulation, a slab edge, a balcony, a parapet, creates a thermal bridge: a path for heat to bypass the insulation entirely. In a house with continuous exterior insulation on the main walls, these details need particular attention, since a thermal bridge at a slab edge or window buck can undo a meaningful fraction of the assembly's overall performance. Structural thermal break products exist for exactly this condition, balcony connections in particular, and should be specified wherever a slab or structural element penetrates the insulation line.

Pour sequencing. Large wall pours are planned in sections to avoid cold joints, a visible seam where one pour has begun to set before the next is placed against it, in locations where the design intends a continuous, uniform surface. The concrete subcontractor's pour plan should be reviewed against the architectural elevations to confirm that any necessary joints land where they are least visually disruptive, or are treated as an intentional design line, a reveal or a change in form-tie pattern, rather than an unplanned seam.

Vibration and consolidation. Concrete is mechanically vibrated during placement to eliminate air voids and ensure it fully fills the formwork around reinforcement, especially at congested areas like lintels and corners. Under-vibrated concrete shows as surface honeycombing, visible voids, once the forms are stripped, a cosmetic and durability problem on an exposed architectural surface.

Section 11. Concrete Mix Design and Curing

Strength. Structural concrete for bearing walls in this building type is typically specified in the 4,000 to 6,000 psi compressive strength range, higher than the 2,500 to 3,000 psi common in basic residential flatwork. The specific value comes from the structural engineer's design, based on the loads calculated in Section 5.

Durability, not only strength. A lower water-to-cement ratio produces a denser, less permeable concrete, which resists water and chloride penetration to the reinforcing steel far better than a higher water-cement-ratio mix of the same nominal strength. For a structure meant to last well beyond a standard design life, the mix specification should target low permeability directly, sometimes specified as a maximum water-cement ratio, commonly around 0.40 to 0.45 for this application, rather than compressive strength alone.

Supplementary cementitious materials. Partial replacement of portland cement with fly ash, slag cement, or silica fume is common practice in durability-focused concrete. These materials refine the pore structure of the cured concrete, reducing permeability, and they reduce the heat generated during curing, the heat of hydration, which matters in thick sections since a large temperature difference between the hot interior of a thick pour and its cooler surface can cause cracking. They also reduce the embodied carbon of the mix, since they substitute for a portion of the cement, the most emissions-intensive ingredient in concrete.

A historical reference point. Roman concrete structures, including structures still standing after roughly two thousand years, were made differently from modern concrete: with volcanic ash as the reactive component rather than portland cement, and, according to research published in 2023 by a team including MIT's Admir Masic, mixed using a hot-mixing process with quicklime that left reactive lime deposits distributed through the material. When the concrete later cracked, water reaching these deposits triggered a reaction that recrystallized as calcium carbonate and filled the crack, a genuine self-healing mechanism rather than a metaphorical one. This is not directly reproducible with standard modern ready-mix concrete, but it is a useful reference point for the underlying design goal: durability engineered into the mix chemistry itself, not only into the structural design. Where budget allows, ask a concrete supplier about durability-focused admixture packages, including crystalline waterproofing admixtures and corrosion-inhibiting admixtures for the reinforcing steel.

Curing. Concrete continues to gain strength for years after the standard 28-day test date; the 28-day figure is a standardized benchmark for specification and quality control, not the point at which the material finishes curing. What matters during the first days after the pour is keeping the concrete moist, through moist curing, curing compounds that seal in mix water, or curing

blankets, and, in cold weather, keeping it warm enough for the cement hydration reaction to continue, since concrete that freezes before gaining sufficient strength can be permanently damaged. Slower, moisture-retained curing produces a denser, stronger, less permeable final material than concrete allowed to dry out quickly. This is a schedule item worth protecting: rushing past the curing period to keep construction on schedule is a common way to compromise the exact durability the whole project is built around.

Section 12. Roof System

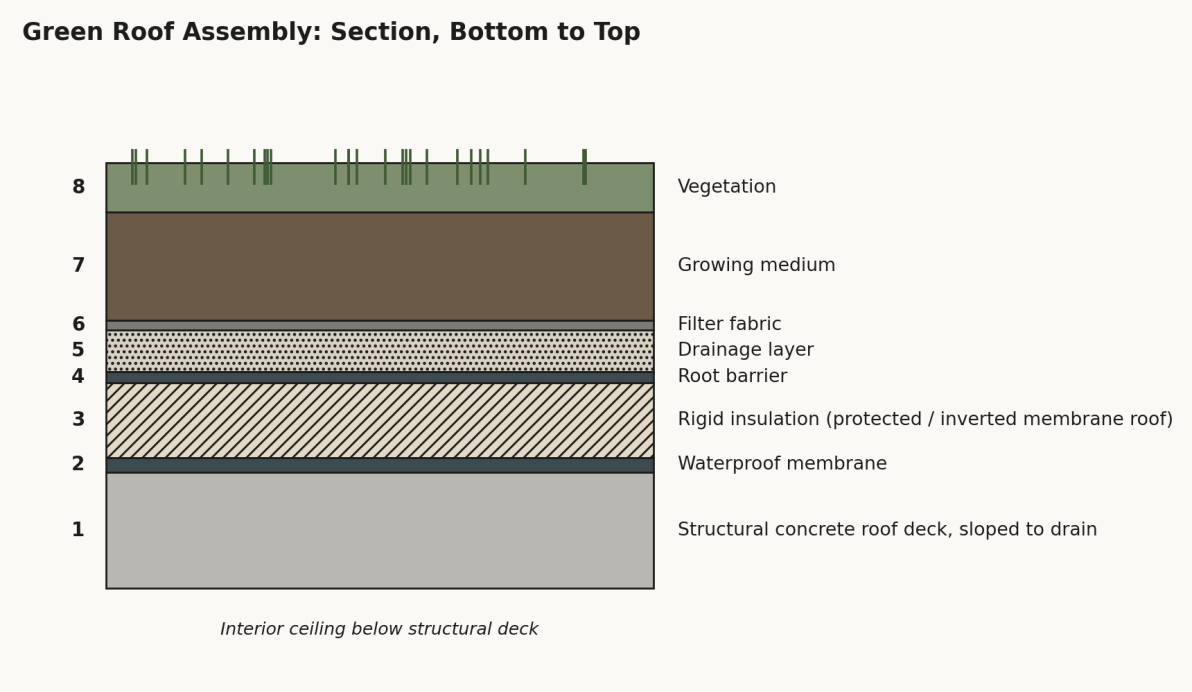

Figure. Green roof assembly over structural concrete deck

The roof deck is a structural reinforced concrete slab, flat or very low slope, spanning between bearing walls as sized by the structural engineer in Section 5. It is also the single highest-risk waterproofing element in the building, since it is horizontal and holds standing water rather than shedding it the way a vertical wall does. Getting the roof membrane detail right matters more than any other envelope decision; a leak here is more consequential and harder to trace than a leak in a wall.

Slope to drain. Even a flat concrete roof needs a minimum slope, commonly around a quarter inch per foot, to move water to drains or scuppers rather than allowing it to pond. Ponding water accelerates membrane degradation and adds sustained load the structural design must account for if it is not eliminated by slope.

Green roof assembly, built up from the structural deck:

1. Structural concrete roof deck, sloped to drain.
2. Waterproof membrane, fully adhered or mechanically fastened per the manufacturer's system, with every penetration, drains, vent stacks, mechanical curbs, detailed and flashed individually.
3. Rigid insulation, placed above the waterproof membrane in this assembly, a protected-membrane or inverted-roof configuration. Placing insulation above the membrane protects the membrane from ultraviolet exposure and from the temperature swings and mechanical wear it would

otherwise face directly under the growing medium and maintenance foot traffic.

4. Root barrier, to prevent plant roots from reaching and eventually puncturing the membrane and insulation below.
5. Drainage layer, typically a molded plastic drainage board or a mineral drainage layer, moving excess water laterally to the roof drains rather than letting it sit against the root barrier.
6. Filter fabric, keeping the growing medium from washing down into and clogging the drainage layer.
7. Growing medium, engineered for green roof use, lighter and more free-draining than ordinary topsoil, at a depth matched to the vegetation selected. A simple sedum or groundcover roof needs as little as 3 to 4 inches; a roof intended to support small shrubs needs substantially more depth and, correspondingly, more structural capacity allocated to it in Section 5.
8. Vegetation.

Leak detection. Because this roof cannot easily be inspected once built up, an electronic leak detection system, a grid of low-voltage wires embedded at the membrane level that can be tested periodically to locate a breach without excavating the full assembly, is a modest additional cost relative to the consequence of an undetected leak in an otherwise inaccessible structural roof.

Portions of the roof without vegetation, over mechanical equipment, or where a standing-seam metal roof is used instead, follow a simpler assembly: structural deck, waterproof membrane, insulation, and the metal roofing system, with solar panels mounted on a penetration-managed rack system rather than ballasted directly on the membrane.

Section 13. Windows, Glazing, and Passive Solar Design

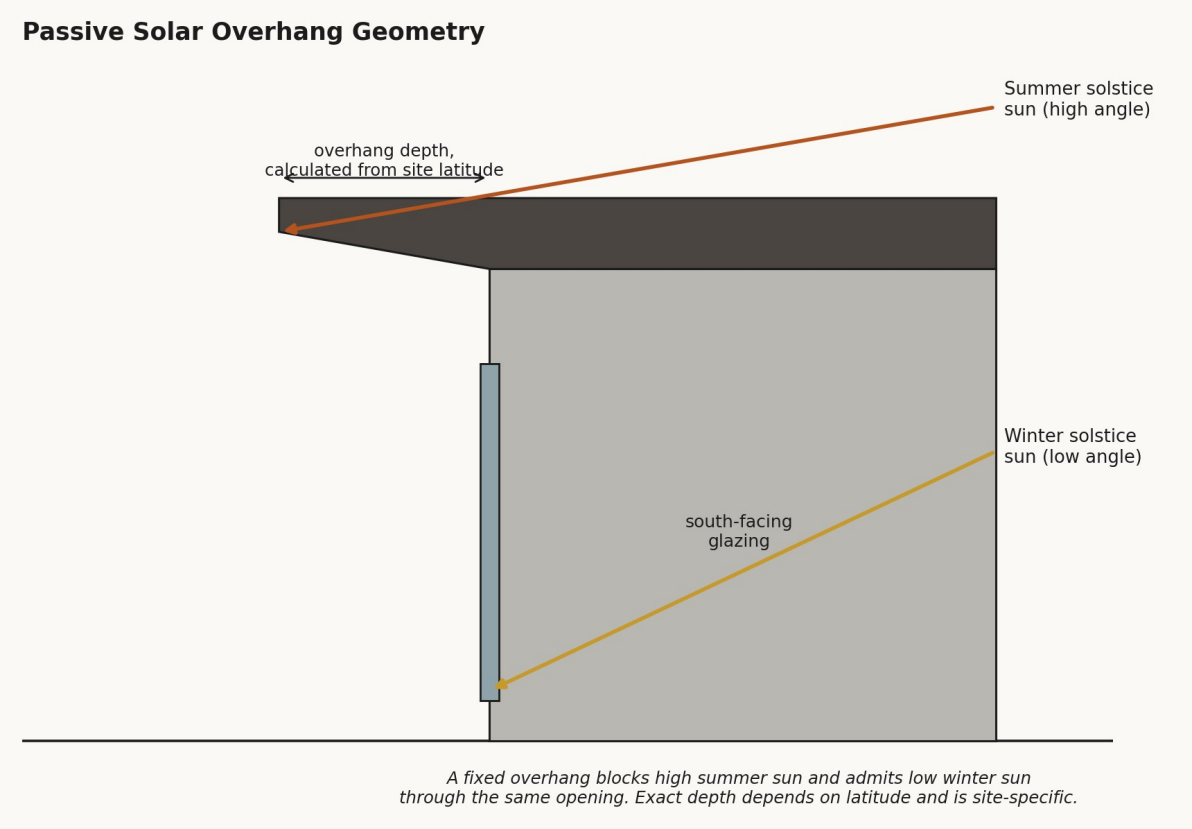
Passive Solar Overhang Geometry
Summer solstice
sun (high angle)
overhang depth,
calculated from site latitude
Winter solstice
sun (low angle)
south-facing
glazing
A fixed overhang blocks high summer sun and admits low winter sun
through the same opening. Exact depth depends on latitude and is site-specific.

Figure. Overhang shading geometry: summer versus winter sun angle

Performance targets. Triple-pane glazing with a thermally broken frame, fiberglass, wood-clad, or a well-designed thermally broken aluminum system, is the baseline for this level of envelope performance. Target whole-window U-factors in the range of 0.20 to 0.25 Btu per hour per square foot per degree Fahrenheit for a high-performance house in most climates, with lower values, toward 0.15, appropriate in very cold climates or for a Passive House-certified design. These figures should be confirmed against the energy model from Section 6, not chosen independently of it.

Solar heat gain by orientation. Solar heat gain coefficient, SHGC, should differ by facade. South-facing glass, intended to collect winter heat, typically uses a higher SHGC, commonly in the 0.40 to 0.60 range, to admit more solar energy. East- and west-facing glass, which receives low-angle morning and afternoon sun that is harder to shade and more prone to unwanted summer heat gain, typically uses a lower SHGC. North-facing glass, receiving no direct sun, is sized for daylight and view rather than solar gain and can prioritize the lowest available U-factor without an SHGC trade-off.

Overhang sizing. A fixed roof overhang above south-facing glass can be sized to block high summer sun while admitting low winter sun, using the sun's altitude angle at the site's latitude on the summer and winter solstice. This is a

standard passive solar design calculation, not a rule of thumb: the required overhang depth relative to window height depends directly on latitude, and the correct value for a specific site should be calculated by the architect or energy consultant using the site's actual latitude, not copied from a design built elsewhere. The general principle, a fixed overhang admitting low-angle winter sun while blocking high-angle summer sun through the same opening, holds everywhere; the specific dimension does not.

Air sealing at the rough opening. Where a window unit meets the concrete rough opening, the air barrier and the insulation must be detailed as continuous around the entire perimeter, with a compatible sealant or membrane bridging the gap between window frame and concrete. This joint is a common air leakage and water intrusion point in an otherwise very tight envelope, and deserves the same design attention as the wall assembly itself, not a generic caulk bead added at the end.

North-facing openings. Minimize glazing area on the north facade to reduce heat loss. This facade contributes little useful daylight relative to its heat-loss penalty, and in the reference layout it is also where privacy from the street or a neighboring parcel typically matters most.

Section 14. Heating and Cooling

The ground-source, or geothermal, heat pump is the mechanical heart of the house, distributing heat through radiant floor tubing embedded in or beneath the polished or exposed concrete floor.

How it works. A closed loop of pipe, buried in the ground, circulates a water-and-antifreeze mixture that exchanges heat with the earth, which stays at a roughly stable temperature, commonly in the 45 to 60 degree Fahrenheit range depending on latitude and depth, year-round, well below outdoor summer air temperature and well above outdoor winter air temperature. The heat pump uses this stable source to heat in winter and reject heat to it in summer, at a coefficient of performance, COP, typically in the 3.0 to 4.5 range, meaning 3 to 4.5 units of heat delivered per unit of electricity consumed. This efficiency holds up in cold weather far better than an air-source heat pump's does, since the ground loop does not get colder the way outdoor air does.

Loop field type. The choice depends on available land and soil conditions, confirmed by the geotechnical investigation in Section 3. A vertical closed loop uses boreholes drilled 150 to 300 feet deep, spaced roughly 15 to 20 feet apart, needed where land area is limited, and generally the highest cost per ton of capacity, particularly in rock, which slows drilling. A horizontal closed loop uses trenches 4 to 6 feet deep across a larger area of land, at lower cost where sufficient land is available. A pond or open-loop system costs less still, where a suitable water body or high-yield aquifer with a legal discharge path exists on-site, though this depends entirely on site-specific conditions most sites will not have.

Sizing. The loop field and heat pump capacity are sized from the Manual J load calculation described in Section 6, not from square footage alone. A well-modeled version of this house, given its mass, insulation, and airtightness, typically needs meaningfully less heat pump capacity than a wood-framed house of the same size, one of the reasons accurate load calculation is worth the modest fee it costs relative to the size of the equipment decision it drives.

Cost, as a planning range. As of 2026, a typical residential ground-source system runs roughly 18,000 to 45,000 dollars installed, with vertical closed-loop systems toward the higher end of that range, roughly 22,000 to 32,000 dollars for the loop alone in average soil, more in rock, and horizontal or pond loops toward the lower end. Costs vary significantly by region, soil and rock conditions, and loop field type; get site-specific quotes rather than budgeting from a national average alone.

Radiant floor distribution. Hydronic tubing, embedded in the slab or in a thin topping layer beneath the finished, often polished or sealed, concrete floor, distributes heat by warming the floor mass itself, which then radiates and convects heat into the room at a low, steady surface temperature. This pairs naturally with an exposed concrete floor and with the house's overall thermal

mass strategy: the floor slab becomes both structure and heat emitter. Radiant systems respond slowly compared to forced air, well suited to a house with high thermal mass and a correspondingly stable indoor temperature, and poorly suited to a house that needs to respond quickly to an intermittently occupied schedule.

Backup and redundancy. A whole-house system with no backup heat source has a single point of failure. Depending on climate severity and risk tolerance, common approaches include a wood stove, a small supplemental electric-resistance element in the heat pump system, or confidence that the generator and battery backup described in Section 17 can cover the heat pump's electrical load during an outage.

Section 15. Ventilation

A tightly sealed, high-performance envelope of the kind this house targets does not exchange air with the outside on its own the way a leakier conventional house does by accident. Controlled mechanical ventilation is not optional in a house this airtight; without it, indoor air quality and humidity are both uncontrolled.

ERV versus HRV. Both an Energy Recovery Ventilator and a Heat Recovery Ventilator continuously exhaust stale indoor air and supply fresh outdoor air, recovering a large fraction of the heating or cooling energy that would otherwise be lost in that exchange, by passing the two air streams across a heat exchange core without mixing them. An ERV additionally transfers moisture between the two air streams; an HRV transfers heat only. In practice, an ERV is generally preferred in climates with significant cooling and humidity loads, since it limits how much outdoor humidity enters in summer and retains some indoor humidity in winter. An HRV is generally preferred in very cold, dry climates, where the concern is more often too much indoor humidity than too little, and where an ERV core can be more prone to frosting in extreme cold depending on the specific unit. This choice should be made with the mechanical designer based on the specific climate, not assumed by default.

Duct design. Ventilation ductwork in a tight envelope should be sized and sealed carefully, since the purpose of the system is a known, controlled airflow; leaky or undersized ducts undermine both fresh-air delivery and the energy recovery the unit exists to provide. Balanced ventilation, matched supply and exhaust airflow, verified by testing at commissioning in Section 22, avoids depressurizing or pressurizing the house relative to outside, which can otherwise draw in unconditioned air or radon through unintended paths.

Section 16. Water Systems

Well. Where municipal water is unavailable, a drilled well is the primary source. Well depth and yield are entirely site-specific, ranging from under 100 feet to several hundred feet depending on regional hydrogeology. The well driller and, in many jurisdictions, a required water test after drilling establish both depth and water quality for the specific site.

Filtration train, in order. Sediment filtration comes first, removing particulate matter, sand, silt, rust, before it reaches downstream equipment and shortens its life. Carbon filtration comes next, removing chlorine where relevant, volatile organic compounds, and taste and odor issues. Ultraviolet disinfection comes last, since UV effectiveness depends on clear water; sediment or organic material upstream of the UV stage can shield pathogens from the UV dose and reduce disinfection effectiveness. UV must follow, not precede, the filtration stages.

Water testing before design finalization is worth doing, since results such as hardness, iron, or specific contaminants can add stages to this basic train, a water softener for hard water or an iron filter, that are easier to plan for than to retrofit into a finished mechanical room.

Rainwater harvesting. Collected from the roof, typically through a first-flush diverter, which discards the initial, most contaminated runoff from each rain event, into a storage tank sized on roof catchment area, regional rainfall, and intended use. Rainwater intended for potable use requires its own filtration and disinfection train, generally more involved than filtration for well water, and is subject to jurisdiction-specific regulation that varies widely. Rainwater for irrigation and other non-potable uses has a much simpler regulatory and treatment path in most places.

Greywater. Recycling water from showers, sinks, and laundry for irrigation reduces total water demand, but regulatory treatment of greywater varies enormously by jurisdiction. Some explicitly permit and even incentivize simple systems, laundry-to-landscape being the simplest, while others require permitted systems with significant treatment, or restrict greywater reuse altogether. Confirm the local regulatory position before including greywater in the design, since it affects both system complexity and permitting path.

Section 17. Electrical and Power Systems

Solar array sizing. Do not pick a system size, 10 kW, 15 kW, or any other figure, before running the numbers. System size should follow from the Manual J-derived electrical load, the Section 14 heat pump plus all other household electrical use, and the site's solar resource, the annual kWh produced per kW of installed capacity, which varies by latitude and local cloud cover, commonly in a range of roughly 1,200 to 1,700 kWh per kW per year across most of the continental United States, lower in cloudier northern regions. An all-electric house with heat-pump heating and cooling generally needs a larger array than an all-electric house without space heating electrified, which is why the 10 to 15 kW range referenced for this design sits toward the higher end of typical residential systems.

Battery storage. Lithium iron phosphate, LFP, chemistry is the dominant choice for stationary residential storage as of 2026, preferred over other lithium chemistries for its safety profile and cycle life, at some cost in energy density relative to weight, which matters far less for a stationary battery than for a vehicle. As a planning figure, installed residential battery cost in 2026 runs roughly 700 to 1,300 dollars per usable kilowatt-hour, meaning a 30 to 60 kWh system, sized for multi-day backup of at least critical loads rather than the whole house at full simultaneous demand, runs roughly in the low tens of thousands of dollars, with meaningful variation by region, brand, and whether the system is retrofit (AC-coupled) or designed in from the start (DC-coupled, generally somewhat less expensive per kWh in new construction).

Backup generator. An automatic transfer switch connects a backup generator, propane or diesel, typically, to the electrical system, engaging automatically if grid power and battery reserves are both unavailable for an extended period. This is a redundancy layer beneath the solar-and-battery system, not a replacement for it, and sizing it to carry the ground-source heat pump's electrical load, not only lighting and outlets, is worth confirming explicitly with the electrical designer if year-round backup capability, including through an extended winter outage, matters to the project.

Centralized mechanical and electrical room. Housing the batteries, inverters, heat pump equipment, ventilation unit, water filtration, and networking equipment in one dedicated room simplifies both installation and future maintenance: every system that will need periodic inspection or eventual replacement, covered in Section 23, is in one place, with dedicated ventilation and access, rather than distributed through crawlspaces, attics, and closets across the house.

Section 18. Interior Construction

The wall assembly resolved in Section 10 leaves much of the interior wall surface as exposed concrete. The design intent for the rest of the interior is direct contrast: warm, tactile materials against the concrete, applied selectively rather than uniformly.

Material selection follows a simple rule: where a surface is touched, sat on, or walked on barefoot, use wood, wool, leather, or stone with those qualities; where a surface is structural or largely unseen, leave it as concrete or steel. This is not a decorating instruction so much as a way of allocating a finish budget, concentrating spend on the materials that carry the most contact and sensory weight, flooring, a reading chair, shelving, a desk surface, rather than spreading finish budget evenly across every surface.

Moisture-sensitive detailing. Anywhere wood contacts concrete directly, sill plates, built-in shelving anchored to a concrete wall, wood flooring transitions, a moisture and vapor break between the two materials prevents the wood from absorbing residual or seasonal moisture out of the concrete. This is a standard detail, and skipping it is a common cause of localized wood decay or fastener corrosion at wood-to-concrete connections.

Section 19. The Library

Structural shelving load. Fully loaded hardcover shelving is heavy: a reasonable planning figure is roughly 30 to 60 pounds per linear foot of shelf, depending on shelf depth and book size, meaning a long run of shelving carries several tons of live load concentrated along the wall it is anchored to. This load should be communicated to the structural engineer explicitly as a design input, not treated as incidental furniture weight, if the library is to hold several thousand volumes as referenced in the original design concept.

A worked example: at 5,000 volumes and an average of roughly 12 books per linear shelf-foot, a reasonable planning average across mixed hardcover and paperback, the collection needs on the order of 400 linear feet of shelving, distributed across however many shelves of vertical height the room provides. At 7 shelves of usable height, that is roughly 57 linear feet of wall run, a plausible library wall length, but the concentrated load per linear foot of wall at any given point is what the structural engineer needs, not simply the total book count.

Environmental control for preservation. Paper degrades faster at high temperature and at high or fluctuating relative humidity. A stable target in the range of roughly 65 to 70 degrees Fahrenheit and 30 to 50 percent relative humidity, held with the least seasonal variation practical, is standard guidance for book preservation, and is a natural byproduct of this house's thermal mass and mechanical design rather than a separate system, provided the mechanical designer is given this target explicitly rather than defaulting to a generic comfort setpoint with wider tolerance.

Light exposure. Ultraviolet and even visible light exposure degrades paper, ink, and binding materials over time, faster on the spines and covers facing a light source. Limiting direct sun exposure onto shelving, through window placement, UV-filtering glazing film, or orienting shelving away from direct light, is a genuine preservation measure, not an aesthetic preference, for a collection meant to last as long as the building.

Fire risk. A concrete structure does not burn. Several thousand books still represent a substantial fire load if a fire starts from any other source: an electrical fault, a fireplace, an external source, inside the room. For a collection of real value, a clean-agent fire suppression system, which extinguishes fire without discharging water or leaving residue across the collection, unlike a standard sprinkler head, is worth pricing and considering, particularly for a segregated archive room as referenced in the original design concept.

Section 20. Acoustic Design

Mass and airborne sound. Thick concrete walls attenuate airborne sound well, following the basic mass law of acoustics: heavier, denser materials transmit less airborne sound energy through them. This is one of the genuine structural advantages of this building type, achieved simply by virtue of the wall thickness already required for other reasons.

Flanking paths dominate in practice. In most real buildings, sound does not travel primarily straight through a thick wall; it travels around it, through paths weaker than the wall itself: windows, doors, duct penetrations, electrical outlet boxes, and any gap where the wall meets a different assembly. A house with excellent wall mass and an unsealed duct penetration, or a hollow-core interior door, can perform far worse acoustically than the wall's mass alone would suggest. Sealing and detailing these flanking paths, acoustic sealant at penetrations, solid-core doors with proper weatherstripping, duct silencers or offset duct runs where ventilation ducts cross between rooms, matters as much as the wall itself.

Decoupling for interior partitions. Where an interior wall separates two rooms with different noise sensitivity, a mechanical room next to the library, for example, a decoupled assembly, resilient channels or a double-stud wall with insulation and no rigid connection between the two wall faces, reduces sound transmission further than mass alone, since it interrupts the vibrational path between the two rooms rather than only adding weight to a single connected wall.

Target metrics. Sound Transmission Class, STC, ratings quantify airborne sound isolation for a given assembly. A standard interior wood-stud wall is often in the STC 30s to low 40s, while a well-detailed heavy or decoupled assembly can reach STC 55 or higher. Ask the architect or acoustic consultant to specify target STC ratings for the assemblies that matter most, the mechanical room walls and any wall between the library or office and the rest of the house, rather than assuming mass alone delivers a specific number.

Section 21. Landscaping and Site Water Management

Three zones, moving outward from the house, serve distinct functions rather than only an aesthetic gradient.

Immediate zone. Hardscape, stone paths, a concrete patio, and low, non-combustible or well-irrigated planting immediately around the structure serve as both a design transition and, in fire-prone regions, a defensible space buffer directly against the building.

Production zone. Orchard, vegetable beds, and a greenhouse, sited to take advantage of the same southern solar exposure that benefits the house, positioned so deciduous trees in this zone can shade south- or west-facing outdoor spaces in summer while losing their leaves and admitting sun in winter, the same passive solar logic from Section 13 extended to the landscape.

Wild zone. Native plants and habitat at the property's edges require less irrigation once established, support local pollinators, and, particularly at a distance from the structure, satisfy defensible-space requirements more easily than a fully wild, unmanaged perimeter would.

Site water management. Grading directs surface water away from the foundation on all sides; a minimum slope away from the building, typically several percent for the first several feet, is standard practice regardless of building type. Swales or dry creek beds manage larger volumes of surface runoff across the site, and rainwater harvested from the roof, Section 16, can be directed to landscape irrigation storage rather than to stormwater drainage, reducing both irrigation demand and runoff volume leaving the site.

Section 22. Testing and Commissioning

Before occupancy, the building's actual performance should be measured, not assumed from the design documents.

Blower door test. Measures the building's air leakage rate, typically expressed as air changes per hour at 50 Pascals of pressure difference, ACH50. A Passive House-level target is 0.6 ACH50 or lower; a strong but more conventional high-performance target commonly falls in the 1 to 3 ACH50 range; most current energy codes require somewhere in the range of 3 to 5 ACH50 depending on climate zone and the code version in effect locally. The test also identifies specific leakage locations, often at window rough openings, electrical penetrations, and the wall-to-roof connection, while the blower door runs, using a smoke pencil or thermal camera to find drafts directly, more useful for fixing problems than the single ACH50 number alone.

Thermal imaging. An infrared camera survey, ideally conducted with a meaningful indoor-outdoor temperature difference, a cold day in most climates, reveals thermal bridges, missing insulation, and air leakage as visible temperature anomalies on interior or exterior surfaces, catching installation defects invisible to the eye once finishes are in place.

Concrete moisture verification. Before applying any moisture-sensitive interior finish over a concrete floor or wall, particularly relevant for polished concrete floor sealers and any adhered flooring, test the concrete's moisture content directly, a calcium chloride test or an in-situ relative humidity probe are standard methods, rather than relying on elapsed time since the pour as a proxy. Sealing a finish over concrete that has not yet released enough of its mix water traps moisture, which commonly shows up later as adhesive failure, sealer delamination, or surface staining.

Systems commissioning. Each system, the heat pump and radiant distribution, the ventilation system, verified for balanced, correctly sized airflow at each supply and exhaust point, the electrical and solar or battery system, and the water filtration train, should be tested and documented as functioning to its design specification before it is considered complete, not simply switched on and assumed to be working. This documentation is also the baseline against which future maintenance and troubleshooting, Section 23, will be compared.

Section 23. Maintenance Schedule

The maintenance schedule reflects the project's central premise: the concrete shell is built to be essentially permanent, while everything else is on a normal replacement cycle for its category of equipment.

Annually. HVAC and heat pump inspection, roof drain and gutter cleaning, a visual check of exterior sealant joints and any visible crack in the concrete surface, and a check of the sub-slab radon system if it was activated with a fan.

Every 5 to 10 years. Resealing exterior joints and penetrations, resealing or refinishing polished concrete floors as wear dictates, and inspecting and servicing mechanical components with a shorter service life than the core heat pump unit itself, circulator pumps, for example.

Every 20 to 30 years. Replacement of the heat pump unit, the battery system, LFP batteries commonly carry cycle-life-based warranties in the range of 10 to 15 years, meaning at least one and likely two replacement cycles over this period, and most electronics and controls, none of which are expected to last as long as the structure.

Every 50 or more years. Window replacement, since even a high-quality window unit's seals and gas fill degrade over decades well before the surrounding concrete does, and any interior renovation the occupants choose to undertake, unconstrained by structural limitations since the shell was designed from the outset to outlast several full cycles of interior finish preference.

The concrete shell itself. Routine inspection, not routine replacement. A well-built, well-waterproofed shell of this type is the one component of the house not on a replacement schedule at all within any planning horizon relevant to a single occupant.

Section 24. Budget Framework

The following figures are 2026 planning ranges for the continental United States, gathered from current contractor and industry pricing data. They vary substantially by region, site conditions, and finish level, and should be treated as a starting point for discussion with local contractors and a professional cost estimator, not as a quote.

Shell construction. Concrete house construction cost, across ICF, board-formed, and precast methods, spans roughly 110 to 700 dollars per square foot depending on method and finish level, with fully custom, architectural-finish concrete construction, closer to what this manual describes, with exposed board-form interior surfaces and a green roof, toward the upper half of that range, commonly 350 to 700 dollars per square foot or more. For a 2,000-square-foot house, this alone suggests a shell-and-envelope construction cost in the rough range of 700,000 to 1,400,000 dollars, before the systems below and before site work, though lower figures within comparable ranges are possible for less elaborate finish treatments.

Mechanical systems. Ground-source heat pump: roughly 18,000 to 45,000 dollars installed, as detailed in Section 14. Solar array: cost varies with system size and regional labor rates; a 10 to 15 kW system is a substantial project-level expense in its own right, separate from the battery. Battery storage: roughly 700 to 1,300 dollars per usable kWh installed, meaning a 30 to 60 kWh system runs from the high five figures into six figures depending on final size and configuration. Water systems, well, filtration train, and any rainwater harvesting infrastructure, add a further site-specific cost, often in the low tens of thousands of dollars depending on well depth and system complexity.

Sitework, permitting, and design fees. Design and engineering fees for a project of this complexity, architect, structural engineer, geotechnical engineer, energy consultant, commonly run in the range of 10 to 15 percent of total construction cost for a fully custom project, sometimes more for a first-of-its-kind design requiring extensive structural and energy modeling. Permitting fees are typically a smaller fraction of the total but should be budgeted alongside a realistic timeline allowance, Section 25, since delay itself has a carrying cost.

Contingency. A minimum contingency of 15 to 20 percent above the base estimate is standard advice for any custom construction project, and is arguably more important here than for conventional construction, given the number of specialized subcontractors and the correspondingly higher chance of at least one unanticipated condition: rock encountered during geothermal drilling, an unexpected soil condition during excavation, a lead-time delay on a specialty window or ICF product.

Overall order of magnitude. Combining shell, systems, sitework, and design fees, a fully realized version of the roughly 2,000-square-foot house described in this manual is realistically a project in the range of 1 million to 2 million dollars

in most U.S. regions as of 2026, with meaningful movement in either direction based on region, finish level, and how much of the off-grid-capable systems package is actually built out versus deferred. Get multiple contractor bids and a professional cost estimate specific to the final design and site before treating any number in this section as a budget.

Section 25. Timeline

- Design and engineering: 6 to 12 months.
- Permitting: 2 to 6 months, running partly in parallel with late-stage design.
- Site preparation and excavation: 3 to 6 weeks.
- Foundation: 1 to 2 months.
- Concrete shell, walls and roof slab: 3 to 5 months, weather-dependent, since concrete placement and curing both slow significantly in cold weather.
- Roof waterproofing and green roof build-up: 3 to 6 weeks.
- Windows and envelope completion: 1 to 2 months, can overlap with late shell work.
- Mechanical systems rough-in and equipment installation: 2 to 4 months, substantially overlapping with interior construction.
- Interior construction and finishes: 4 to 8 months.
- Landscaping: 2 to 4 months, and can extend beyond occupancy for planting that establishes over multiple seasons.

Total, ground-up to occupancy: 18 to 30 months is a realistic range for a project of this complexity, longer than a comparable conventional house due to the additional design, permitting, and specialty trade coordination involved, and highly dependent on how many of these phases a given contractor can run in parallel rather than in strict sequence.

Section 26. Common and Costly Mistakes

- Using standard ICF above grade where an exposed interior concrete surface is wanted. Covered in depth in Section 10, and worth restating as the most common conceptual error in this building type.
- Missing conduit or plumbing sleeves before a pour, discovered only after the concrete cures.
- Skipping the geotechnical report, or treating its recommendations as optional, and sizing footings from a generic table instead.
- Insufficient roof slope, leading to standing water and accelerated membrane failure on the single most consequential waterproofing surface in the building.
- Sizing the heat pump from square footage rather than from a Manual J calculation specific to the actual envelope, producing an oversized, short-cycling, inefficient system.
- Skipping the hygrothermal moisture model on the wall assembly, risking trapped moisture in a wall type that behaves differently from a standard wood-framed wall.
- Treating library shelving load as furniture rather than as a structural design input.
- Rushing the concrete cure to protect the schedule, at the cost of the durability the entire project is designed around.
- Choosing a contractor on general residential experience without confirming direct experience in exposed architectural concrete finish work specifically.
- Failing to rough in radon mitigation before the slab is poured, then facing a disruptive retrofit if a later test shows elevated levels.

Appendix A. Design and Construction Team Checklist

- Architect with concrete residential experience
- Structural engineer, licensed in the jurisdiction of construction
- Geotechnical engineer
- Energy consultant or Passive House-trained designer
- General contractor with architectural concrete experience
- Concrete or formwork subcontractor, may be separate from the general contractor
- Mechanical designer, Manual J, geothermal, ventilation
- Electrical designer, solar, battery, backup power
- Well driller and, or septic designer, as applicable
- Geothermal loop contractor
- Solar and battery installer
- Landscape designer, particularly for defensible-space or permaculture-zone planning

Appendix B. Glossary

- **ACH50**: air changes per hour at 50 Pascals pressure difference, the standard metric from a blower door test.
- **COP**: coefficient of performance, units of heat delivered per unit of electricity consumed by a heat pump.
- **ERV, HRV**: Energy or Heat Recovery Ventilator, mechanical ventilation units that recover energy from exhaust air.
- **ICF**: Insulated Concrete Forms, stay-in-place foam formwork for concrete walls.
- **LFP**: lithium iron phosphate, a battery chemistry common in residential storage.
- **Manual J**: the standard North American method for calculating residential heating and cooling loads.
- **SHGC**: Solar Heat Gain Coefficient, the fraction of solar energy admitted through a window.
- **STC**: Sound Transmission Class, a rating of airborne sound isolation for a building assembly.
- **U-factor**: a measure of heat transfer through a window or assembly; lower values indicate better insulation.
- **WUFI**: a widely used hygrothermal, heat and moisture, modeling software for building assemblies.